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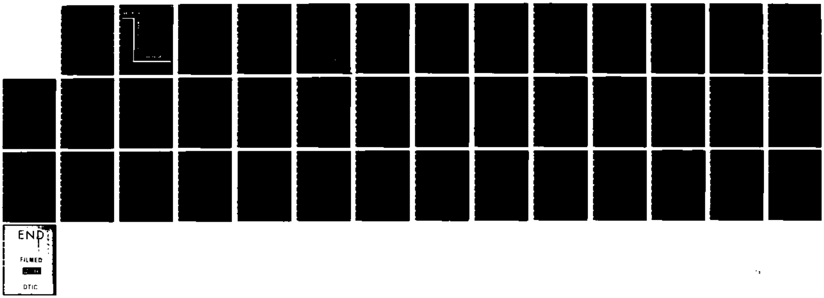

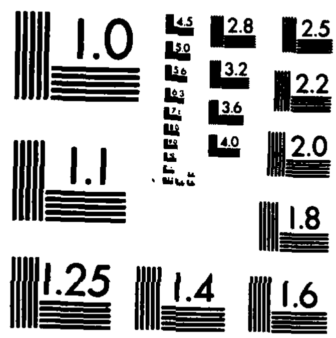
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ACQUIRING BETTER MAINTENANCE TRAINERS: LESSONS LEARNED IN THE F-16 SAMT STUDY

By

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This paper presents lessons learned about how to design future maintenance trainers as well as how to conduct training and cost effectiveness studies. Information presented includes background information on the trainers and the F-16 Training Program and cost effectiveness of maintenance trainers in general and of the Simulated Aircraft Maintenance Trainers (SAMTs) in particular. Also included in this paper are specific lessons learned in the areas of trainer design, trainer evaluation, and training systems.

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This publication is primarily a working paper.
It is published solely to document work performed.

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Section 1: Introduction

Applied Science Associates recently evaluated the F-16 Simulated Aircraft Maintenance Trainers (SAMTs). The study included both training effectiveness and cost effectiveness, and a formal and informal evaluation of two instructional features of the SAMTs. A representative subset of the SAMTs was studied. Students and instructors shared their opinions and experiences, and student task performance data were collected and analyzed.

Although the information gathered in the study was not always conclusive, many interesting lessons were learned about how to design future maintenance trainers, as well as how to conduct training and cost effectiveness studies. The purpose of this paper is to present these lessons. Section 2 presents background information on the trainers and the F-16 training program; Section 3 discusses the cost effectiveness of maintenance trainers in general and of the SAMTs in particular; and Sections 4 to 6 present specific lessons learned in the areas of trainer design, trainer evaluation, and training systems. The lessons learned are written such that each section can stand alone; the paper need not be read cover to cover; i.e., this paper is designed to be a reference document for System Program Office (SPO) acquisition managers. An index is provided at the end to facilitate use of the paper as a reference document.

This paper is a summary of the F-16 SAMT study. Study results will be documented elsewhere in future papers and reports.

Section 2: Background Information

The F-16 SAMTs are used in Field Training Detachment (FTD) courses. Students in these courses are either 3-levels directly out of technical school (sometimes after other assignments) or 5- to 7-levels who have experience either on other aircraft or other systems. The courses are not self-paced and the instructor is present at all times. After the FTD course, students participate in On-the-Job Training (OJT).

Five trainers used in four different FTD courses were studied. One of the trainers was configured as a cockpit and the others were typical flat panel trainers. These trainers were selected from the set of 12 because they could be made available for the study, and they represented the two types of trainer configurations found in the set. Each trainer consists of a master console (containing the computer and the instructor controls) and panels [or, in the case of the Engine Run trainer, a three-dimensional (3-D) mockup] representing the simulated system. Each trainer also has a built-in slide projector. The courses in which the trainers are used have an average of five students per class and range in length from 3 days to several weeks. The following trainers were evaluated:

TFE-2 Avionics Flight Controls
TFE-4 Electrical Systems
TFE-10 Engine Start
TFE-11 Engine Diagnostics
TFE-12 Engine Run

The TFE-10 and TFE-11 are used in the same course, and for most purposes will be considered together. The Pneudraulics trainer was also initially targeted for study but was not included due to the decision to move the trainer to resident school.

As stated previously, the complete results of the evaluation will not be discussed in this paper. However, it should be mentioned that overall the results of the study speak well for the effectiveness of simulation in maintenance training. High percentages of students passed all of the tasks investigated and passed by standards more exacting than those adopted by the FTD. That is, the proficiency needed to pass a task in the evaluation context was often greater than that needed to pass the course. Also, the attitudes of both students and instructors were generally positive toward the trainers. For example, the instructors generally agreed that using the SAMTs made teaching less difficult and improved the quality of instruction. Specific negative responses and ineffective features mentioned later in this paper should be balanced against these generally positive findings.

Section 3: Trainer Cost Effectiveness

The cost effectiveness portion of the F-16 SAMT study had several goals. The first was to determine the total life cycle costs for each selected SAMT. That is, it was planned to calculate not only the acquisition cost, but also operation and maintenance costs. These calculations were to include the costs of the trainers' instructional features. Another goal of the cost study was to estimate the costs of equivalent Actual Equipment Trainers (AETs). That is, the study was intended to determine acquisition, operation, and maintenance costs for hypothetical AETs that could be used to meet the same training objectives as did the F-16 SAMTs. These estimated AET costs were to be compared with the determined costs for the trainers.

Unfortunately, these goals proved to be difficult to meet. The cost data available to the study were extremely limited. Most of the data made available to the study were received toward the end of the study, so that only limited analysis was possible; however, some conclusions could be drawn. The methodology and findings of the cost effectiveness portion of the study are briefly described in the following sections.

3.1 Life Cycle Costs

The cost model used in the study is not described in detail here, as it is adequately documented elsewhere. However, the concept of life cycle costs must be understood. Rather than comparing trainers solely on the basis of acquisition costs, it is important that costs over the entire life of the trainer be considered. That is, one trainer that initially costs more than another might be less costly to operate and maintain, and so prove to be less costly overall. In the SAMT study, acquisition, operation, and maintenance costs were considered for: (a) facility, (b) equipment, (c) materials, (d) personnel, (e) supply, and (f) miscellaneous.

Data were not available for all factors; however, when possible, each area will be addressed in the following sections.

3.2 SAMT Acquisition Costs

The acquisition costs for the five SAMTs under study are reported in Table 1. These costs were derived from a list of prices of SAMTs delivered to several different sites. The costs reported in Table 1 are average (mean) unit costs. The average costs were computed by information provided by the F-16 System Program Office (SPO). The

costs reported to the F-16 SPO by equipment prime contractors were not consistent, making it difficult to compute a meaningful average. For example, some unit costs included administrative and some included research and development (R&D) costs. Unfortunately, these costs were not listed as line item costs; thus, they could not be separated from the total unit price in a precise way. The average unit costs reported in Table 1 were computed by averaging the price of units which did not include any additional charges (administrative and R&D costs). The vendor administrative and R&D costs listed in Table 1 were derived by subtracting the average unit costs from all those unit costs where these additional costs were included. All the unit costs reported in Table 1 include delivery charges, which could not be separated from the total unit costs because of the nature of the data provided to the F-16 SPO.

As Table 1 clearly shows, in all cases the R&D costs were much greater than the unit price of the trainers. R&D costs (and the listed vendor administrative costs) are one-time costs. If many trainers are to be acquired, a relatively low unit price will outweigh high, one-time costs. For a comparison with expected acquisition costs for an AET, see Section 3.3.4.

Table 1. SAMT Acquisition Costs

	Average Price (Including Delivery)	Approximate Vendor Administrative Costs	Approximate R&D Costs
Avionics	$357,565	$170,338	$2,137,807
Electrical	261,332	75,932	1,251,783
Engine Start	175,024	105,208	1,132,174
Engine Diagnostics	333,431	209,926	2,294,180
Engine Run	195,035	206,067	1,268,091

3.3 AET Comparison

In the cost study, each of the five trainers was compared with a hypothetical AET. This involved generating hypothetical designs for the AET that could be used to meet the SAMT's training objectives. In this paper, the findings for the Engine Run course will be emphasized. The next section (Section 3.3.1) briefly discusses comparative costs per student hour for all the courses; the following sections discuss the hypothetical Engine Run AET, and how it compared with the Engine Run SAMT.

3.3.1 Relative Costs Per Student

A small amount of cost data was available to the study, asid rom the acquisition data. Although the data were limited, estimates (relative costs per student and per student hour could be generate(These estimates for the SAMTs and AETs in all four courses are presented in Table 2.

Only those operation and maintenance costs which could be estimated for both the SAMTs and the hypothetical AETs were included. These costs consisted of the following: facility maintenance costs, instructor salaries, vendor maintenance costs, and fuel costs for supplementary training. The largest single factor was the cost of fuel, which is incurred for AET training, but not for SAMT training. It was logically determined, by analyzing the hypothetical AET designs, that facility maintenance costs would be higher for the AET, and instructor salaries would be equal for the two training systems. Vendor maintenance is an additional cost incurred by SAMTs but not by AETs, since an AET is typically maintained by Air Force personnel rather than vendors. It is worth noting that costs per student and per student hour are higher for the AETs in all cases.

These factors, as they apply to the Engine Run course, are described in more detail in the following sections.

3.3.2 AET Design for Engine Run

In order to estimate costs associated with the hypothetical AET, it was necessary to generate a hypothetical design. Obviously, an AET could take many different forms which might vary widely in cost. Based on the training requirements of the Engine Run course, a single possible design was chosen and was used as the basis for cost estimates.

Table 2. Known Relative Costs Per Student

SAMTs vs. AETs

	Cost Per Year		Students Per Year		Cost Per Student		Training Hours Per Student		Cost Per Student Hour	
	SAMT	AET	SAMT	AET	SAMT	AET	SAMT	AET	SAMT	AET
Engine Run	$37,720	$474,420	200	200	$188.60	$2372.10	18	18	$10.48	$131.78
Engine Diagnostics	37,720	916,495	75	67	502.93	13679.02	156	186	3.22	73.54
Electrical	37,720	181,920	120	116	314.33	1568.28	96	108	3.77	14.52
Avionics	37,720	37,520	90	83	419.11	452.05	150	150	2.79	3.01

The hypothetical design for the Engine Run AET consists of an actual F-16 cockpit with a full set of controls and displays. Those components which are powered by the aircraft battery would be fully operational, while those dependent on the engine would not be functional. That is, the AET would have electrical power equivalent to that of the aircraft, but would not contain or simulate an engine.

The hypothetical design has various implications for acquisition, operation, and maintenance costs. The expected costs for this AET are contrasted with the Engine Run SAMT costs in the following sections. The design also has implications for training, as will be discussed in Section 3.4.

3.3.3 Engine Run Life Cycle Costs

The known life cycle costs for the Engine Run SAMT and corresponding hypothetical AET are reported in Table 3. The costs listed in Table 3 do not represent all of the costs associated with either type of trainer. However, several of the most important cost factors (such as fuel costs) are included. It is believed that the costs included in the table are indicative of the total relative costs. That is, although the totals listed are less than actual expenses, they show the areas where the costs of the AET would be greater or less than the costs of the SAMT. The derivation of the estimated costs is presented in the following sections.

3.3.4 Acquisition Comparison

The unit price of the hypothetical AET would be greater than the unit cost for the SAMT. The SAMT, however, would have a much greater R&D cost. As shown in Table 3, the cost for the first unit (including R&D) would be much higher for the SAMT. Over the first four units, however, the costs would balance out. For the next four units, the SAMT per unit cost would be much lower. Thus, the cost effectiveness of the trainers would depend in part on how many units were purchased. In this case, if more than four units were purchased, the SAMTs would be less expensive overall, despite higher initial costs. Although these particular numbers are specific to the Engine Run SAMT and hypothetical AET, this pattern would be expected to apply to other cases. That is, a simulator would usually have high R&D costs, but low per-unit costs; thus, in the long run simulators will tend to cost less than AETs.

The unit costs, vendor administrative costs, and R&D costs for the SAMTs were derived from cost data provided by the F-16 SPO, as explained in Section 3.2. The unit cost of the AET was harder to estimate.

Table 3. Known Life Cycle Costs

Engine Run SAMT vs. Hypothetical AET

	SAMT	Hypothetical AET
Acquisition		
- Unit Price	$ 195,035	$ 500,000
- Vendor Administrative Costs	206,067	206,067
- R&D	1,268,091	100,000
Total Acquisition Cost,		
First Unit:	1,669,193	806,067
First Four Units:	2,254,798	2,306,067
Second Four Units:	780,140	2,000,000
Operation and Maintenance		
- Instructor Salaries	35,120	35,120
- Fuel Cost	0	437,500
- Vendor Maintenance	1,400	0
- Air Force Maintenance	--	--
- Spare Parts	10,667	27,778
Total Yearly Operation and Maintenance Cost:	47,187	500,398
Modification		
- Update Costs	390,070	50,000
Total Estimated Cost, First Year, First Unit:	2,106,450	1,356,465
Second Unit:	630,292	1,050,398

Several F-16 trainers utilizing some actual equipment exist, such as a canopy system trainer, a cockpit procedures trainer, and an egress trainer. The prices of these trainers ranged from $375,000 to $600,000. The figure $500,000 was chosen as a representative figure. Other AETs have cost as much as $700,000 to $1,000,000. Thus, $500,000 is fairly conservative, although not the lowest possible figure.

It was arbitrarily assumed that costs for design reviews would be approximately the same for the AET and the SAMT. The figure for R&D for the AET was derived from data on a F-16 canopy system AET. For that trainer, the price of the first unit was $100,000 higher than for later units. It is assumed that this difference represents R&D costs. (That is, research and development associated with determining what components of actual equipment to use, how they are to be modified, etc.) This figure, although arbitrary, seemed to be a reasonable estimate for the Engine Run AET R&D cost.

3.3.5 Operation and Maintenance Comparison

Many factors influence operation and maintenance costs. Data were available for only a few of these factors. Instructor salaries were estimated (based on a 1981 wage rate) for two full-time instructors (for 1 year) in both the SAMT and the AET courses. Fuel cost for AET supplementary training was estimated by calculating the pounds of fuel used in an average engine run (1,750), times the number of students yearly, at a rate of $1.25 per pound. Note that this is a conservative estimate, since more than one practice run per student might be necessary.

The calculations for maintenance costs do not include maintainer salaries, since, for both systems, maintenance is performed by instructors. The estimated cost for SAMT vendor-provided maintenance was derived from figures provided by personnel at Hill AFB and McDill AFB. Similarly, data on the number and kind of spare parts needed yearly for the SAMT were provided, from which a cost figure was derived. It was difficult to obtain such data for the AET. The figure listed in Table 3 for the AET was obtained by assuming that the relative cost of units and spare parts would be the same for SAMT and AET. That is, spare parts for the SAMT were known to cost about 18 percent of the unit price. Thus, the figure listed for AET spare parts represents 18 percent of the unit price. Note that the SAMT figure was not for an entire spares package but for parts actually used.

3.3.6 Modification Comparison

The costs associated with modifying the SAMT (especially SAMT software) is known to be high. Specific cost figures were not available, but informal estimates made by Air Force personnel ran as high as 2 1/2 times the initial acquisition cost. Vendor modifications are necessary to keep the trainers up to date and useful because the SAMT does not have local update capabilities. (See Section 4.4.)

For SAMT updates, the cost figure listed in Table 3 is twice the unit price. The cost listed for AET updates is 10 percent of the acquisition cost. This estimate was based on the number and kind of Engineering Change Proposals (ECPs) that the F-16 aircraft has in an average year. The estimated total yearly costs for the first unit and for the second and all following units include yearly update costs, as well as acquisition and yearly operation and maintenance costs. Note that costs for the first unit, which include R&D costs, will be higher for the SAMT, but for later units, the AET cost is higher.

3.4 Value for Training

The comparisons discussed above relate only to cost, not to training benefits. However, it is important to remember that training value will vary also. For instance, the AET cannot present emergency tasks in the way a simulator can. Using the AET, the instructor might talk-through emergency symptoms and procedures, but the student cannot actually practice recognizing and responding to malfunctions. Also, as previously mentioned, it was assumed that AET students would practice a normal engine run on the aircraft. However, on the SAMT, students can have many opportunities to practice the run, rather than just one chance.

More practice on the actual aircraft could be provided, at greater cost. However, hazardous tasks really cannot be practiced on actual equipment. Thus, in certain ways a simulator will probably always have greater training value than an AET. The extent of this depends on the nature of the aircraft system and the tasks to be trained.

Section 4: Trainer Design Issues

This section presents several lessons learned, both positive and negative, which relate to design features of the SAMTs. These lessons are categorized into the following areas: fidelity levels, instructional features, hardware design, trainer maintenance and update, and task selection. Note that these lessons learned do not cover every feature of the trainers; rather, they are issues that happened to emerge in the course of the study.

4.1 Fidelity Levels

The issue of fidelity surfaced many times in the study, and the results were interesting. The trainers in the four courses under study varied in their fidelity levels. While degree of fidelity is difficult to measure precisely, relative fidelity was estimated logically by talking to instructors and students. Instructors (n=6) were asked which of the trainers had the highest and lowest fidelity. The trainer that was considered most realistic was the Engine Run trainer, which is a 3-D representation of an F-16 cockpit. Most of the controls and displays are functional. The panel trainer considered lowest in fidelity was the Avionics trainer. The Engine and Electrical trainers were rated toward the middle of the fidelity continuum. In addition to overall fidelity, trainers were also rated as to their relative fidelity regarding operational checks and malfunction simulation.

4.1.1 General Findings

Several training effectiveness measures were collected and analyzed. One of these was a self-rating by the students of their confidence in performing tasks after training, both on the aircraft and on the SAMTs. Students rated their own confidence, on a scale of one to seven, in performing specific tasks in their subject field. That is, students from the Engine Diagnostics course rated their confidence in performing Engine Diagnostics tasks; similarly, students from the other courses rated their own confidence for tasks related to the subsystem they had studied. The tasks that were rated fell into two broad categories: fault isolation and operational checks. Figure 1 shows the average confidence reported by students in each course, for each type of task.

The information in Figure 1 can be examined trainer by trainer. For two of the courses, confidence in performance on the aircraft was higher for fault isolation tasks; for the other two, confidence was

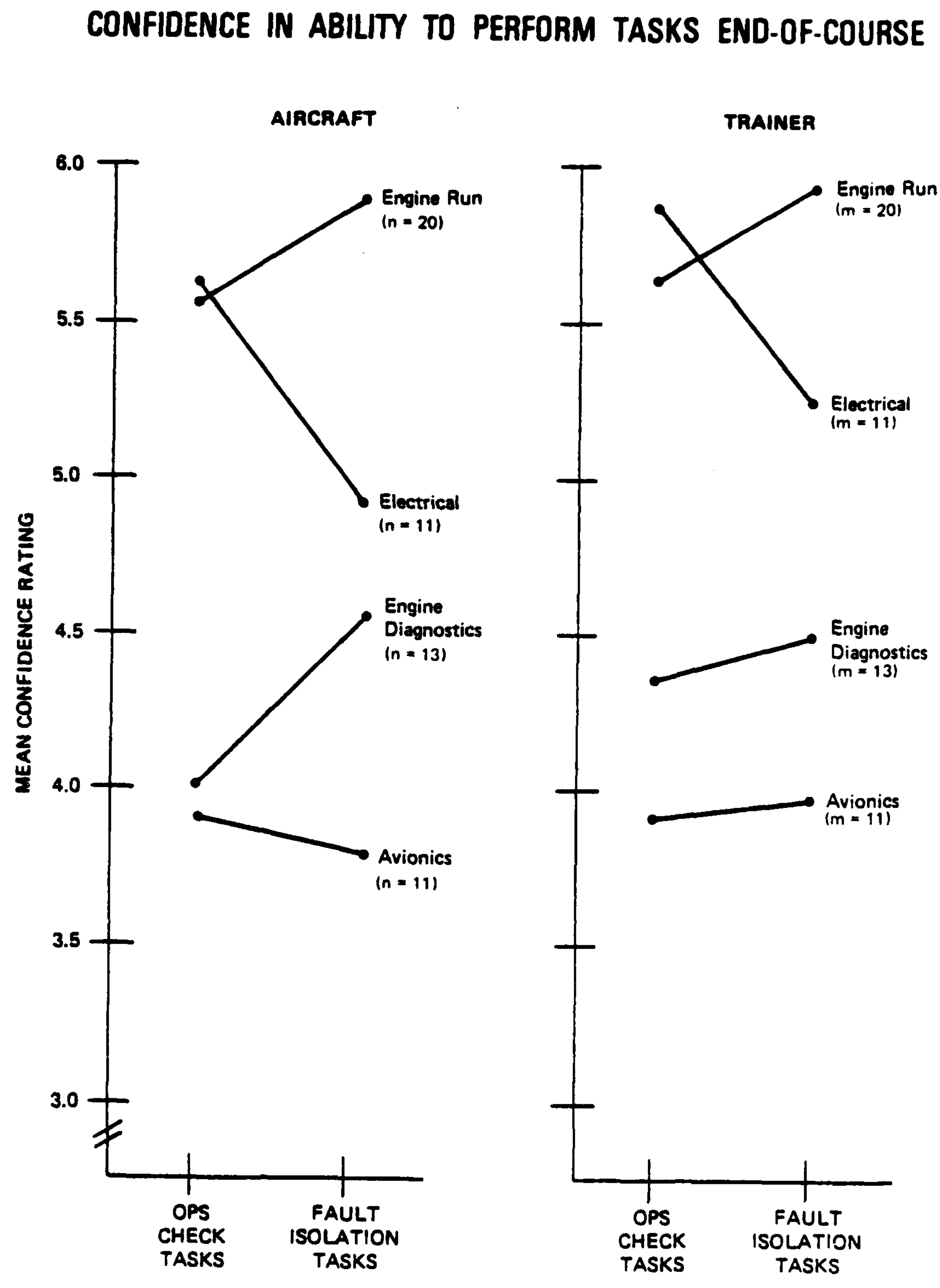

Figure 1. Confidence in Ability to Perform Tasks End-of-Course

higher for operational checks. This correlated with the fidelity levels reported by instructors. That is, trainers that were reported to have higher fidelity in operational checks than in malfunction simulation produced higher levels of confidence in operational checks; and vice versa. For instance, the Engine Diagnostics trainer, which reportedly has high fidelity malfunction simulation, produced much higher levels of confidence for troubleshooting tasks than for operational tasks.

The information in Figure 1 can be used to compare trainers, but only if certain assumptions are made. The reader must decide if these assumptions are valid, in order to decide whether to consider the data in this way. The first assumption is that tasks of a given type have common characteristics and can be compared. That is, an operational check involves following procedures, locating aircraft components, interpreting test equipment readings, and so on, regardless of the specific subsystem involved. In that light, an Engine operational check can be compared to an Avionics system operational check. The content is different, but the type of task is the same. The second assumption is that the tasks chosen for comparison were of approximately equal difficulty. The researchers attempted to choose such tasks, with the assistance of instructors and other Subject Matter Experts (SMEs). However, it is still an assumption the reader must make.

If the reader chooses to consider the data in this way, the information in Figure 1 can be seen as comparing the confidence levels of students taught on different trainers. These data also correspond to the reported fidelity levels. That is, the Engine Run trainer, reported to be the highest in fidelity, produced the highest confidence levels overall; the Avionics trainer, reported to be lowest in fidelity, produced the lowest confidence.

In addition to the confidence ratings, data were also collected on actual student performance. These data were obtained by observing actual task performance, and recording errors. An error was defined as omission or incorrect performance of a procedural step. The inability to answer an important question about a step was also considered an error. Certain errors were flagged as "critical," specifically those that could cause damage to the aircraft or create a safety hazard. Common errors included: (a) the inability to locate an aircraft component and (b) skipping a step or sequence of steps. The proportion of errors made by students in each course, for the two types of tasks discussed above, are presented in Figure 2.

Note that, as with the confidence ratings, scores on observed tasks varied from course to course. The information in Figure 2 may be considered trainer by trainer, as an indication of each trainer's

relative effectiveness in teaching operational checks and fault isolation. If the reader chooses to make the assumptions specified above, the data in Figure 2 show that, as with confidence ratings, the trainer with the highest fidelity, Engine Run, produced the best scores (fewest errors). The trainer with the lowest reported fidelity, Avionics, produced the most errors.

Instructor attitudes followed this pattern as well, with the Engine Run trainer being very well liked and the Avionics trainer liked much less than any of the others. In general, instructors seemed to feel that their trainers would be improved by increasing fidelity, especially in terms of more realistic malfunctions and more varied troubleshooting capabilities. (For more details on instructional features, see Section 4.2.)

It should be noted that the SAMTs are relatively low fidelity simulations of an F-16 aircraft. The preference for the higher physical fidelity SAMT does not mean that fidelity should necessarily be as high as is technically possible. It suggests, however, a limit on low fidelity. That is, when fidelity becomes too low, a maintenance trainer may no longer be an effective training medium. Certain task elements apparently are not learned well on low fidelity devices, as will be discussed in more detail below. Certainly, instructor acceptance may become a problem when physical fidelity is low.

As an example of the kind of extremely low fidelity that created problems, some task segments and components are represented on the SAMTs by pushbuttons. The pushbutton steps were often forgotten by students, even when the represented task segements (such as "perform safe for maintenance check") were critical (i.e., would create a safety hazard if omitted).

4.1.2 Teaching Component Locations

In general, the SAMTs were very poor for teaching location of components. The design of the trainers included graphic representations on the panels and associated slides, which were designed to show students where components are located on the actual aircraft. However, the slides typically showed closeups of the components, and as such, could teach appearance but not location. This could be, in part, a specification problem. If slides are intended to teach location, it must be clearly stated in the trainer specifications that the slides should show more than a closeup of the component. If slides and panel graphics (as typically used on flat panel trainers) are not sufficient to teach location, as the SAMT data suggest, some alternative method should be used when component location is an important part of a course. For instance, a scaled-down mockup might be used along with a panel, or actual aircraft time might be planned. (See Section 6.2.)

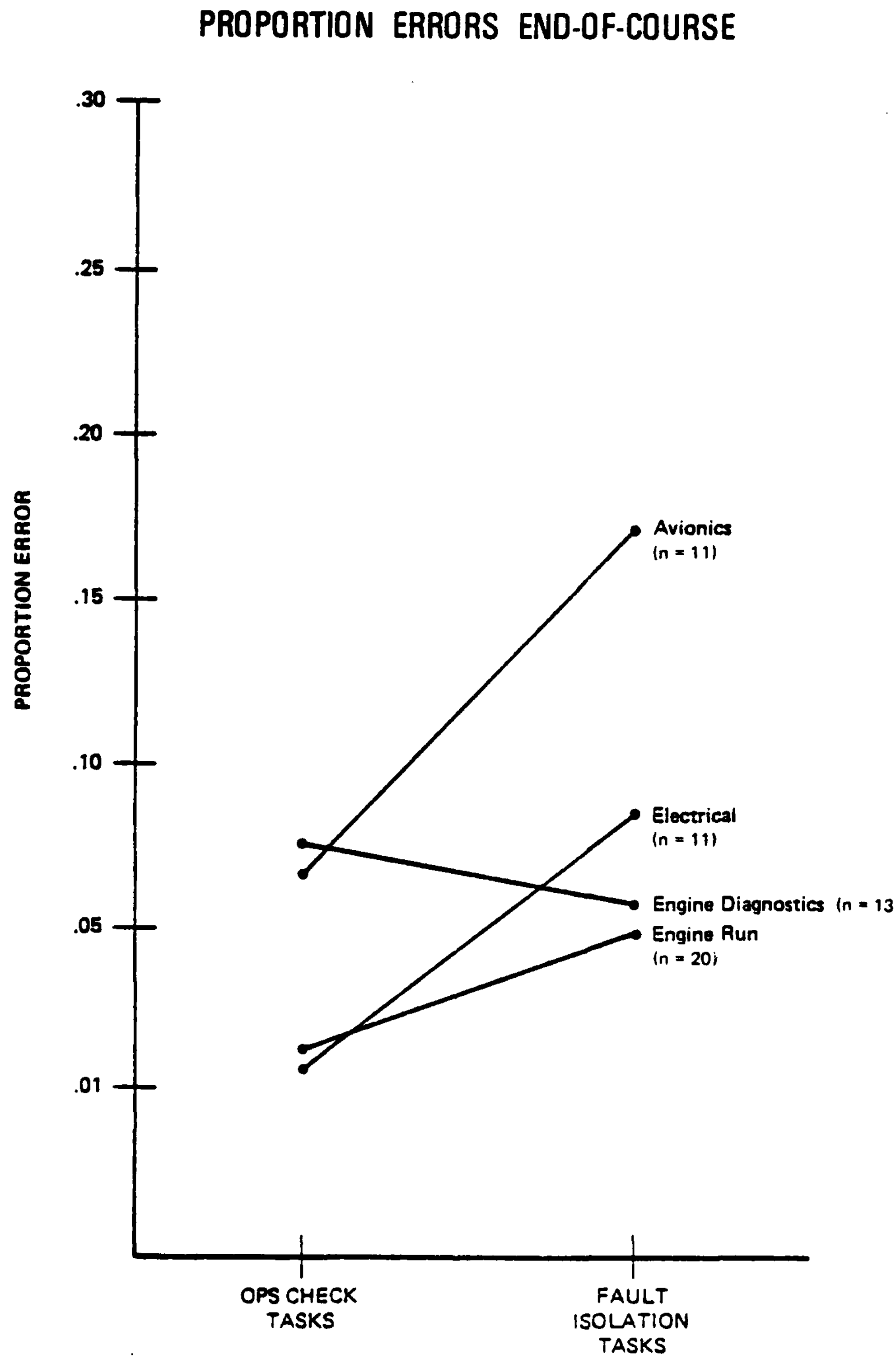

Figure 2. Proportion Errors End-of-Course

4.1.3 Teaching Difficult Manipulations

In some cases, students repeatedly made errors on certain task steps that involved components that were simulated with fairly high fidelity (as judged by the evaluator). In these cases, the task steps involved extremely sensitive manipulations requiring a high degree of skill. It seemed that, for difficult steps of this type, even slightly reduced fidelity can cause problems. For example, the throttle on the Engine Start trainer was designed with reduced fidelity, on the assumption that students would have been previously exposed to the high fidelity Engine Run trainer. However, some of the tasks taught on the Engine Start trainer required more smooth throttle manipulations than those involved in a standard run. Perhaps each component on a trainer should be simulated in accordance with the most difficult task involved. That is, fidelity levels of components on a trainer should perhaps be determined by analyzing the most difficult task to be practiced regularly on the trainer using the component of interest. Component fidelity level should not be determined by finding the average fidelity needed for all the tasks to be trained, as is typically done in most design efforts.

4.1.4 Modeling

A final point which emerged very clearly had to do with the trainers' computational modeling. In general, the SAMTs were modeled on Technical Order (T.O.) procedures, rather than on system data. The exception was the Engine Diagnostics trainer, which closely approximated the actual system. Modeling by the T.O. caused problems in terms of keeping the trainers up to date as flightline procedures changed. The F-16 maintenance concept is procedure oriented, making modeling by T.O. seem reasonable. However, the problems caused were severe, as the simulation was often incorrect. This raises the issue of how best to keep a trainer current with the operational equipment being used on the flightline. A trainer that is out of date is annoying to the instructors and confusing to the students. The low fidelity modeling is an even greater problem in the implementation of automatic student monitoring, as will be discussed in Section 4.2.2.

4.2 Instructional Features

Two instructional features of the SAMTs were critiqued by instructors: malfunction insertion and automatic student monitoring. Instructor responses concerning these two features indicated that malfunction insertion was generally well liked and that student monitoring was universally disliked. The possible reasons for these differing responses are discussed below.

4.2.1 Malfunction Insertion Feature

The responses to automatic malfunction insertion were extremely positive in three out of the four courses. Instructors felt that malfunction isolation could be taught more effectively on the SAMTs than on AETs, since it would not always be possible to create malfunctions in the actual equipment. The ability to show students the behavior of a malfunctioning system, and to emphasize the results of student actions in a realistic context, was noted as one of the best features of a trainer. It is worth noting that the evaluators had difficulty obtaining comparative data on the feature, because instructors were "sold" on the importance of this feature and, in fact, were unwilling to teach without it.

However, the malfunction feature of the SAMTs is not always perfect. Instructors noted that sometimes malfunctions were simulated incorrectly, or procedures programmed into the trainer were out of date. (See Section 4.1.4.)

Some comments of the instructors in the Avionics course were particularly negative. Their main criticism did not seem to be that the malfunctions were badly simulated, but that the appropriate troubleshooting strategy could not be used on the trainer. That is, the trainer did not allow wiring checks, which are the main on-the-job troubleshooting method. Interestingly (even though they were otherwise quite negative about the malfunction feature) the Avionics instructors stated that malfunction capability was the most important feature of the trainer. Part of their negative response seems to stem from a feeling that something important is not working as it should. The suggestion here is that trainers must be designed with an eye to real-world troubleshooting methods, as well as realistic modeling of system responses.

It should also be noted that the malfunction exercises are pre-programmed. Instructors would have liked to be able to change these pre-programmed exercises to make them more realistic (or current with flightline procedures). In addition, the instructors expressed the desire to create new malfunction exercises. Currently, the SAMTs do not have either of these capabilities. (See also Section 4.4.)

4.2.2 Automatic Student Monitoring Package

The automatic student monitoring feature is part of an instructional features package that includes automatic freeze and multiple level cueing. Instructor responses were obtained for all the features in the package.

The responses to this package were overwhelmingly negative. The most common response was that it is not used at all. A number of negative points seem to have led to this lack of utilization.

One point is that the monitoring feature is "all or nothing"; that is, when monitoring is turned on, every action is monitored. At the end of the session, all of these data are reported to the instructor. This large amount of information is difficult to read and interpret. The instructors would have preferred to be able to select the actions to be monitored.

Again, the modeling of the student monitoring was based on the T.O. (See Section 4.1.4.) However, the instructional features were based on later T.O. versions and were not consistent with the rest of the trainer. Furthermore, at a certain point, neither the main simulation nor the student monitoring was consistent with current technical orders. The confusion caused by this is easy to imagine. Several T.O. versions had to be kept on hand, and the instructors had to try and explain the inconsistency.

There were various points mentioned about error messages. The messages specify an error only when it is critical; otherwise, the message states only that an error was made. Also, for non-critical errors, the message does not appear until the end of the task. This can be frustrating for the student, who finds, at the end of the task, that he/she made an error, but does not know what it was. In some cases, since the system models out-of-date technical orders, a correct current procedure may be called an error by the trainer. Instructors have the capability to change error messages, but only for a session, not permanently. This means that the same incorrect message must be changed each time an exercise is presented to the student.

Similar problems were noted with the automatic freeze. Sometimes, the out-of-date modeling would cause a freeze on a correct action. Instructors would have liked to have the ability to change error conditions, both for messages and for simulator freeze. The freeze feature cannot be disabled, so instructors cannot shut it off even when they know it will react incorrectly. (See Section 4.6 for further discussion of the freeze feature.)

The cueing feature was also a problem, but in this case, it seemed a problem of instructor training. The multi-level cueing was evidently designed to be used with a successive approximation strategy. That is, at the beginning of training, students would be given many cues, and as training progressed, cues would be reduced until, at the end of training, only those cues available on the job would be seen. The instructors' response to cueing was that it was not realistic because

the earlier cues would not be available on the job. This comment indicates a possible lack of understanding of the way the feature is supposed to be used. Probably, the instructors were not given the kind of training and documentation that would allow them to use this feature effectively.

Another point mentioned about the cueing feature is that the messages are presented on the instructor Cathode-Ray Tube (CRT). This configuration, although economical, was disliked by the instructors. The instructor station can be turned such that the student can see the CRT while at the panel, but then the student can also see instructor commands to the trainer. A second CRT would have been beneficial.

A final point about the cueing feature is that instructors mentioned they could see no difference in the levels of cueing. This may be a fundamental problem in the design of the cueing feature (i.e., the cueing messages were really too similar from level to level), or it may reflect the desire of the instructors to be able to change messages. That is, possibly instructors just did not like the particular messages that were provided.

One feature that was liked is lesson chaining, (i.e., the ability to preprogram a sequence of tasks). This feature was noted as saving time and improving the flow of instruction.

It should be noted that instructors did not want the instructional features package to begin with. They felt that, since they are always in the room to observe the student, the feature was not needed. This fact, combined with a lack of training and documentation, and the legitimate problems noted above, was enough to ensure the feature would not be used. The answer, in part, is to provide better instructor training. Also, greater control over error conditions, messages, and monitored actions would improve instructor acceptance. (See also Section 4.4.)

A final point worth mentioning is that this instructional features package increased the SAMTs' need for computer storage to such an extent that a costly change from floppy disks to hard disks was required. Considering also the expenses associated with developing the package, it seems that a lot of money was, perhaps, not wisely spent, since the features are so rarely used.

4.3 Hardware and Software Design

Several lessons were learned about trainer hardware and software design. Again, these lessons do not represent a complete analysis of trainers. Rather, these are details that emerged in the course of the study.

4.3.1 Component Interchangeability

One SAMT feature that is considered excellent is the ability to "swap" components. That is, the control console and components of the control console are generally identical from SAMT to SAMT. So, if one trainer has a control console malfunction, the trainer can be operated by borrowing another console, or by replacing a bad component with a borrowed one, until a replacement is obtained. This feature is recommended for future sets of trainers. It was noted that occasionally some minor configuration differences interfered with this practice.

The capability to exchange master consoles had one minor drawback. Since the time totalizer for the trainer as a whole was on the master console, the hours of use of each trainer were not clearly recorded when consoles were "swapped." If console interchangeability is specified, it is recommended that separate time totalizers for consoles and panels be specified also.

4.3.2 Computational System Reliability

The majority of maintenance required on the SAMTs involved the computer. Maintenance of the computational system is a difficult area for instructors/maintainers, and in the case of the SAMTS, vendor assistance is often required to correct computer-related malfunctions. This is costly and increases downtime, since vendor personnel must be brought in. Also, even when the fault might be repaired by instructors/maintainers, the computer parts typically needed are not readily available. Reliability data for two different sites were very dissimilar, with Hill AFB reporting few problems with the SAMTs, and McDill AFB reporting many. However, in both cases, the computational system was noted as the cause of most problems. Also, instructors at both bases stated that the maintenance documentation was not sufficient. (See Table 4; also see Sections 3.3.5 and 6.3 for further discussion of trainer maintenance.)

The answer to the problem of computer reliablity is not clear-cut. However, at the very least, it is apparent that care must be taken in specifying the computational system design. Also, the "swapping" capability described above could help alleviate recurring computer faults, by permitting one trainer's computer to be used for another trainer in the event of malfunction.

4.3.3 Computer Peripherals

Several of the peripheral devices on the SAMTs seemed to be inadequate. For instance, the floppy disk storage proved to be too

Table 4. Parts for SAMTs at McDill AFB

from 1 March to 30 November 1981

Component	Number of Replacements
CPU Boards	5
GPI Boards	10
MDC Boards	2
Memory Boards	27
SIP	3
CRT	3
Line Printers	2
MAST Components	2
Disk Drive Components	1
Battery Back-up	2
Lamp Driver	4
I/O Control	1
A/O Converter	1

limited when instructional features were added. (See Section 4.2.2.) It was also mentioned that the single CRT configuration was a problem. (See Section 4.2.2.) Additionally, it was noted that the thermal printer, while adequate for limited use, would have been a problem if use was expanded. For instance, if student monitoring was used more often, or if the printers were used during updates, the thermal paper, which is difficult to fold and to write on, would have created difficulties. Because the instructors dislike the printer, they have learned how to "fool" the computer so as to disable the printer.

The suggestion here is that future expansion of functions should be assumed when selecting peripherals. That is, specify devices which have a growth capability.

4.3.4 Use of Slide Projector

Another useful feature of the SAMTs had to do with the slide projectors. Each SAMT has an associated slide projector, that shows slides of components upon student request during a simulation training session. The slide projectors could also be operated manually, such that they could be used independently during other parts of the course. This type of flexibility was found to be useful, and is recommended whenever devices such as slide projectors are to be utilized with a simulator. Note that this consideration might also apply to film projectors, videotape players, etc., depending on the specific trainer design.

4.3.5 Trainer Software

The SAMTs' software is completely transparent to the student; that is, the student is not aware of how the simulation works. This type of design is considered good. The student does not require much training in how to use the trainer and can concentrate on the tasks to be learned, without being distracted by the workings of the training device.

It is not known whether the SAMT software is designed in such a way that it could be reused. That is, it is possible that some of the simulation or instructional features software could be used in future trainers. If so, the cost of developing software will be less in future acquisitions.

4.4 Update Capability

The SAMTs have very little capability for update by the instructors (or instructors/maintainers). Especially because of the modeling

problems, the simulation was often out of date. (See Sections 4.1.4 and 4.2.2.) The capability to perform on-site updates, rather than having to wait for vendor modifications, would have saved time and money. Even a fairly limited capacity for instructors to define or modify exercises would have increased the instructors' ability to work around incorrect simulation. This need for greater instructor control of simulation seems to be a recurring theme. (See Section 4.2.2.) Both instructor acceptance and instructional value would be increased with greater instructional control.

It should be noted that the capability to select values or alter parameters is not the same as the need to do so. Instructors should not have to worry about the simulation all the time, but should at least be able to change those points which require changing. This suggests, for instance, that default values for selectable parameters should always be provided.

4.5 Design for the Training Context

A couple of points were noted about the tasks simulated and the general approach to training. The trainers' design does not seem to have been perfectly matched to the training situation; two examples are provided in the next two paragraphs. (See Sections 4.5.1 and 4.5.2.)

4.5.1 Choice of Equipment to Simulate

In studying student task performance, it was noted that certain tasks did not seem to have been taught at all. For instance, students were completely unfamiliar with two different test sets included in two of the SAMTs. Somehow, the decision had been made to include those test sets in the trainers, despite the fact that the instructors do not actually use them. The problem seems to be that instructors do not necessarily teach all tasks listed on a course syllabus. It appears that the instructors believe that only certain tasks require practice. The tasks believed to require practice will be taught using the simulator and others will not.

To avoid including items in the trainer that will not be used, greater instructor involvement in the design process is needed. It is known that at least one instructor (in each system) was used as a Subject Matter Expert in the SAMT design process. It might be better to have several instructors from each field, perhaps with one as the main consultant.

4.5.2. Student Level

When the SAMTs were initially installed, they were used primarily for conversion training (that is, taking personnel qualified on one aircraft and training them or exposing them to the aircraft of interest). Later, the primary use was training 3-levels directly out of technical school. It was mentioned to the evaluators, in conversations with SPO personnel, that the SAMTs had been basically designed with conversion training in mind, since that was to be their first use. In general, conversion training will occur during the first 3 or 4 years in the life cycle of a weapon system. Also, it has been suggested that 3-levels may have more need for hands-on practice than do higher level technicians. It would have probably been better to design for the lowest level student expected to use the trainer over its life cycle. This is not to suggest that higher level students do not benefit from simulator training, just that 3-levels get the most benefit from it and, during the life of the trainer, will represent the largest group of students; therefore, it should be designed to that level.

4.6 Trainer Operation

In general, the instructors had few complaints about trainer operation procedures. However, it was noted that the initialization procedures were too complex. The system had to be "booted up" before exercises could be loaded, which required that two separate floppy disks be inserted. The initialization procedures took between 5 and 10 minutes to complete. This was a problem because the system had to be reinitialized after a freeze. Initialization procedures should be as brief as possible, and the freeze capability should not require reinitialization.

Section 5: Trainer Evaluation Issues

The connection between evaluating trainers and acquiring trainers is sometimes forgotten. It is necessary to evaluate past trainers to know which features are good and which are not, so that the good ones can be acquired again, and the bad ones avoided. In other words, trainer evaluations result in an improved capability to acquire good training devices. This section presents lessons learned about conducting trainer evaluations.

5.1 Cost Reporting

The evaluators had a great deal of difficulty obtaining cost data, for a number of reasons. (See Section 5.2.2.) One of the main factors, however, was the fact that cost data were simply not reported to the Air Force in a usable form. That is, the data were not reported in a form suitable for use in a cost analysis. For instance, there was no way to determine how much of the SAMTs' costs were related to the instructional features.

It appears that this gross level of cost reporting is standard in the military environment. The planned use of the data is to monitor acquisition costs, so more detailed data are not required from contractors. This has several implications for conducting cost studies. For instance, the use of standard forms will probably not be adequate. That is, military personnel involved in the study will have to be willing to record additional information for the study, not just the data they always record. (For further discussion on the use of military personnel in evaluations, see Section 5.2.)

It is conceivable that a cost model could be developed that would make optimal use of the available data. However, only so much can be done without adequate information. Because of this, it is probably necessary to change Air Force cost reporting procedures, if effective cost studies are to be performed. Cost reporting procedures must be developed that will allow useful data to be extracted, and contractors must be required to use these procedures. Standardizing the procedures will allow comparisons to be made easily and directly.

5.2 Data Collection

Collecting data in the military training environment always presents certain difficulties. The experiences of the F-16 SAMT study provide information about what problems can occur and how to get around them.

5.2.1 Training Effectiveness Data

A number of small problems, and one major difficulty, were associated with the collection of training data. These problems emerged even though the study was carefully planned, research agreements were made early, and a pilot study was done to identify any potential problems. Unfortunately, as the study continued, problems emerged which were thought to have been previously resolved or accounted for. Each of these is discussed below.

Several problems caused delays in the collection of training effectiveness data. Data collection took about twice as long as originally planned. An example of the type of problem encountered was that initial data on student flow were incorrect. The data overestimated the proportion of eligible 3-levels in the classes and did not take into account the large number of foreign students who were trained at Hill AFB during the evaluation. Since it was desirable to have all students with a similar background, this faulty information resulted in incorrect planning. It took much longer than expected to get enough students (even when 5-levels were included).

Another example is that the evaluators could not obtain working test sets for hands-on evaluations, even though this was a condition specified in the research agreement. Reasonably enough, the priority was for test sets to be used in maintenance. However, the unavailability of test sets for use in the evaluation caused many delays. Again, initial information had indicated that the test sets would be available.

Delays tended to snowball, and to cause other unforeseen problems. For instance, because the evaluation took longer than expected, some data collection forms had to be updated; this caused more delay. Also, students were sometimes transferred off base shortly after training, so if their task performance was not observed immediately (because a test set was not available), they would be gone and the data could not be collected.

These experiences suggest that time estimates for data collection must be made with extreme caution. Probably, the best initial estimate should be doubled to allow for unforeseen problems.

The major problem, however, was limited resources. The data collection efforts involved personnel at FTD, Tactical Air Command (TAC), and several Aircraft Maintenance Units (AMUs). The many different lines of authority involved made communication and control very difficult. Although cooperation was usually excellent, problems occasionally occurred. Air Force personnel not directly under the authority of evaluation contacts tended to be less cooperative.

Presumably, personnel with responsibilities of their own may consider an evaluation of a device they do not even work with to be a low priority.

Although FTD instructors were extremely helpful, they were reluctant to change their teaching methods for evaluation purposes. For instance, they did not want to teach without the malfunction capability because they believed it was useful and important. However, this made it nearly impossible to obtain comparative data on the effectiveness of the feature.

The F-16 SAMT study had extremely limited resources and could not have personnel on-site full time. The experiences described above suggest that evaluations cannot be successfully done under those conditions. (See also Section 5.2.2.) Much greater resources would have been needed even to monitor how instructors were teaching, much less enforce evaluation guidelines. Furthermore, in some cases, conducting evaluations in the actual training environment simply may not be feasible. That is, in some cases, it may be necessary to set up an artificial situation, rather than using actual students in actual training courses. This, too, would require that greater resources be devoted to a study.

5.2.2 Cost Effectiveness Data

Obtaining usable cost data can be extremely difficult. Military guidelines make it nearly impossible for one contractor to review cost figures from another (even if the two contractors are not in competition). Often, a contractor cannot obtain the release of sensitive information. Also, data may contain hidden variability. For instance, the downtime figures reported to the F-16 SAMT study did not allow for console swapping. (See Section 4.3.1.)

These problems suggest a couple of different remedies. First, high level military personnel should be involved in the cost study, rather than just contractor personnel. Also, someone should be on site full time to track down cost data. Air Force accounting procedures make it necessary to trace information through many individuals and branches, to get the whole picture. In the F-16 SAMT study, the resources to do this were not available. This suggests that Air Force accounting procedures and/or procedures used by vendors to report cost data to the Government should be studied. The data reported by vendors should be in a format that is usable in a detailed cost analysis.

Section 6: Training System Issues

A training device cannot be designed in isolation from the training context. The lessons that are presented in this section have to do with the F-16 training program, and with Air Force maintenance training in general.

6.1 Procedural Approach

The F-16 maintenance concept emphasizes procedure-following, rather than a system logic approach. In observing student task performance, it was found that students often had little understanding of system logic. Frequently, they could not explain task steps. That is, when they were following a procedure, they often did not know what the steps were for or how they related to the system being checked.

This lack of understanding of system logic may not be a major problem. Since the maintenance concept emphasizes procedures, it can be argued that technicians do not need to understand the underlying theory of what they are doing. However, there is a point where system knowledge becomes essential. Procedures cannot cover every possible fault in a complex system. It should be noted that instructors believe that system logic is important and try to stress it; however, the F-16 courses are not designed with this emphasis. Although the issue is open to question, the evidence does suggest a lack in the training of maintenance technicians. A strong empahsis on system logic would be expected to produce better technicians, who can troubleshoot systems more effectively and efficiently.

6.2 Aircraft Time

Students in the F-16 courses stated that they would like to have spent more time working on the actual aircraft. Although they liked the trainers and did not want less time on the SAMTs, they also felt that they learned more in OJT working on the aircraft than they had in the SAMT courses. Observations of task performance also suggested that greater exposure to the aircraft might have been helpful. (See Section 4.1.2.)

Although the suggestion seems to be that these particular simulators add to training, they cannot entirely replace experience on and exposure to the actual aircraft. Courses utilizing trainers should be designed with this in mind.

In the case of F-16 training, OJT is supposed to provide actual aircraft exposure and practice. However, quite often the 3-levels in OJT performed few of the tasks they were supposed to be learning. More experienced technicians tended to do the complex maintenance tasks,

while the OJT students swept the hangar or cleaned up spilled hydraulic fluid. Obviously, most students were learning something and some students got a lot of practice at skills they needed to acquire. However, their utilization varied widely from unit to unit, and some students got very little useful practice. In order for OJT to be an effective and consistent learning experience, perhaps more structure is needed.

6.3 Trainer Maintenance Job

The SAMTs are maintained by instructors, with occasional vendor assistance. This works fairly well, because the Electrical and Avionics instructors, as Subject Matter Experts in their fields, have skills that can be transferred to maintaining the trainers. In cases where instructors do have applicable knowledge, it makes sense for them to be responsible for trainer maintenance.

However, the maintenance of the trainers is essentially done in the instructors' spare time. They are scheduled to teach 6 hours a day, with 2 hours for preparation. This does not leave time for trainer maintenance.

It is difficult to tell exactly how burdensome this is. Data from two different sites varied greatly, as shown in Table 5. However, even if only a few hours a month are spent on maintenance, it seems unfair for those hours to come from instructors' free time.

The alternative is to set up a separate job position for the maintainer. The basic idea of using instructors as maintainers seems to work. An instructor could be put in charge of both routine maintenance and major courseware changes. Having an instructor in this position would assure that the concerns of the devices' users were addressed. In addition, having the instructor/maintainer freed from teaching duties would assure sufficient attention was given to device management. Note that the choice of having one person serve as a full-time maintainer is arbitrary. Depending on maintenance requirements, more or less time would be needed. The point is that maintenance of the trainer should not be done in someone's spare time.

Table 5. Average Maintenance Hours per Month

SAMT	Hours Reported at Hill AFB (1981)	Hours Reported at McDill AFB (1982)
Engine Run	4.3	38.1
Engine Diagnostics	6.3	42.4
Engine Start	2.6	18.8
Electrical	1.1	58.5
Avionics	2.6	15.4

Section 7: Conclusion

The original purpose of this study was not only to collect data on the SAMTS, but also to gather information to assist future design and research efforts. The SAMT evaluation did indeed learn much that is pertinent to trainer acquisition planning as well as trainer evaluation. Many aspects of the study were difficult to conduct; but often the difficulties themeselves were informative. It is hoped that the "lessons learned" presented in this document will be of interest and assistance.

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